Creep, failure and shear banding in a phase separating system

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In the last decades the understanding of the steady state flow of disordered matter has greatly improved. The current physical picture is based on the idea of local shear transformations that induce long-range elastic deformations in the system leading to complex correlations of the yielding regions. The steady state is not reached instantaneously and, depending on the applied force, transient regimes, preceding the material failure, can last for very long time. This is the case of creep experiments: for an applied stress close to the yield stress, one usually observes an extremely slow increase of the strain which can eventually lead to the material failure, in the form of homogeneous flow, shear banding or ductile/fragile fracture. This behavior before failure is rather generic and in particular sublinear creep has been reported in several systems, such as dense colloidal suspension and gels [1]. Yet, the microscopic scenario from the very first stage of the creep up to the onset of flow is still an open issue.

In this work, we use large-scale MD simulations to investigate the mechanical response of a simple glass-forming system under the effect of an external stress. At sufficiently low density, a deep quench leads to a system with a gel-like bicontinuous structure that is fully arrested in the limit where thermal fluctuations are negligible [2]. Here, as the applied shear stress increases, the system response changes from creep deformation, with power-law dependence on time, to macroscopic failure; for intermediate stress values reentrant solid-like behavior is reported (see Fig. 1). While this scenario is stable with respect to the choice of temperature T and density ρ, the creep exponent is not universal as its specific value depends on T, ρ and the applied stress. In particular a deeper quench results in a change from power-law to logarithmic creep. Further, steady flow is observed only for larger densities, approaching the dense regime, in which the gas phase occupies disconnected bubbles inside the dense one. Heterogeneous flow takes place in the form of a shear band localized in a small region close to the cavity.

Our approach, based on microscopic simulations, allow the study of creep dynamics and failure at the atomic level, overcoming the limitations of the experiments on this subject. We show that macroscopic creep is connected to particles inability to diffuse: the large part of the system is virtually arrested whereas few mobile particles constitute sparse cluster located at the interfaces between dense and gas phases. Finally, focusing on microscopy dynamics, we investigate the possibility to predict the onset of macroscopic failure.

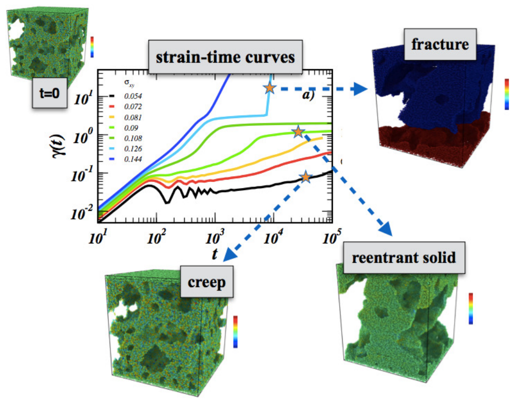

FIG. 1. Main panel: response of the systems to applied shear stress, as described by the time evolution of the shear strain. Depending on the stress value, different behaviors are observed, ranging from creep deformation to resolidification or fracture. Typical particle configurations are shown.

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